# Recent developments at DLR's Calibration Home Base

P. Gege, A. Baumgartner, K. Lenhard, T. Schwarzmaier

Deutsches Zentrum für Luft- und Raumfahrt (DLR)
Institut für Methodik der Fernerkundung, Oberpfaffenhofen, 82234 Wessling, Germany

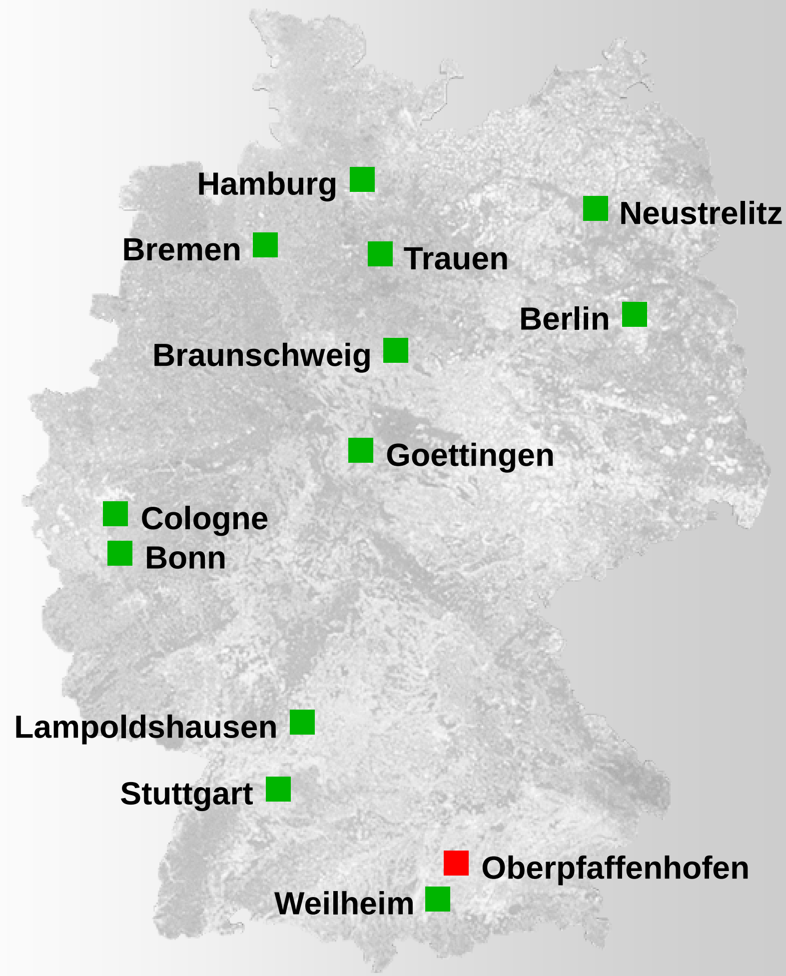
**Conference on "Challenges in the inland water remote sensing - future sensors, improved processing methods",**
**1-6 April 2014, Tartu, Estonia**


DLR

# DLR – German Aerospace Center

6700 employees across
33 institutes and facilities at
13 sites.

Offices in Brussels,
Paris and Washington.



# Recent developments at DLR's Calibration Home Base

## Overview

- Original concept and set-up
- Realization of geometric, spectral and radiometric measurements
- Results for HySpex
- Recent upgrades
- Equipment for water applications
- Conclusions

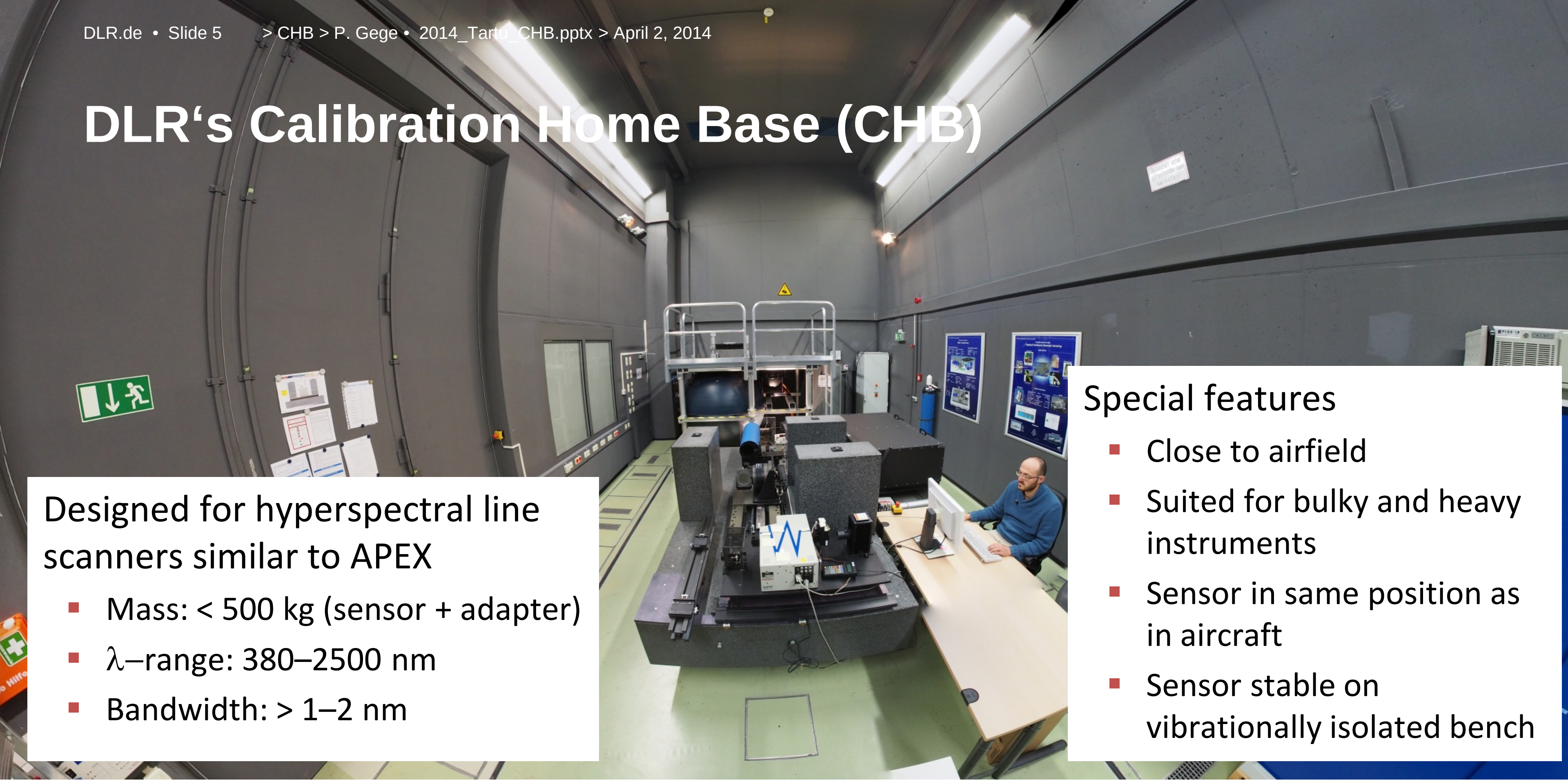
DLR

# DLR‘s Calibration Home Base (CHB)

- Funded partly by ESA to establish **Calibration Home Base (CHB)** for APEX
- Operational since 2007
- Used for geometric, spectral and radiometric measurements
- Available to third parties

DLR

# DLR‘s Calibration Home Base (CHB)



Designed for hyperspectral line scanners similar to APEX

- Mass: < 500 kg (sensor + adapter)
- $\lambda$–range: 380–2500 nm
- Bandwidth: > 1–2 nm

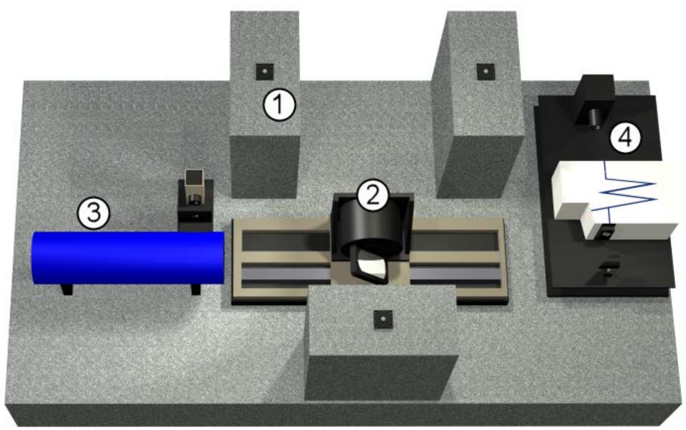
Special features

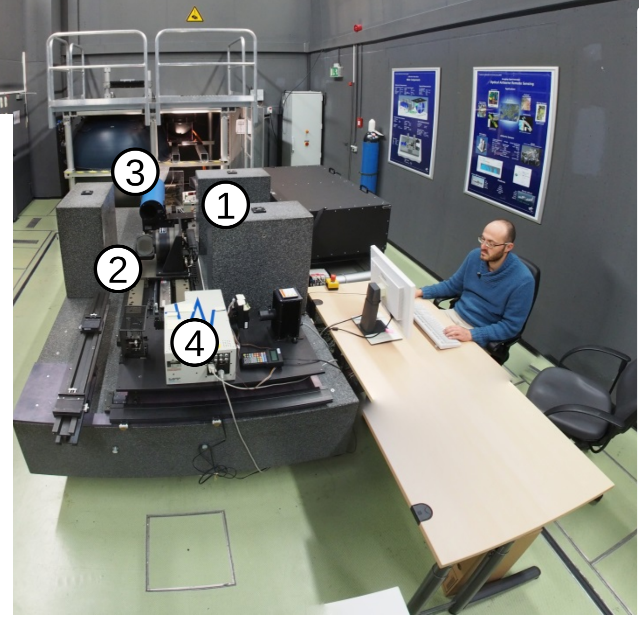
- Close to airfield
- Suited for bulky and heavy instruments
- Sensor in same position as in aircraft
- Sensor stable on vibrationally isolated bench

- Funded partly by ESA to establish **Calibration Home Base (CHB)** for APEX
- Operational since 2007
- Used for geometric, spectral and radiometric measurements
- Available to third parties

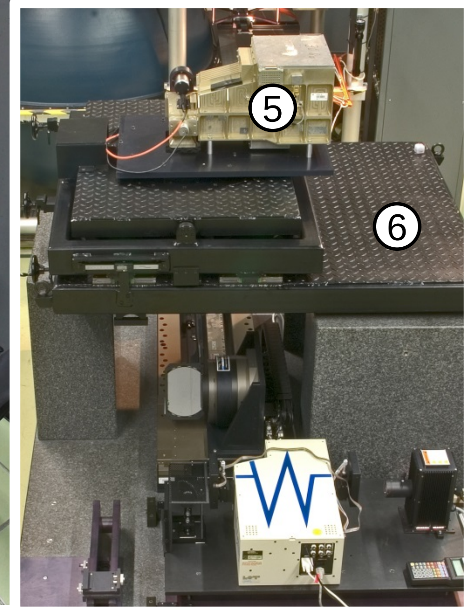
DLR

# Folding mirror concept




Sensor mounted on optical bench

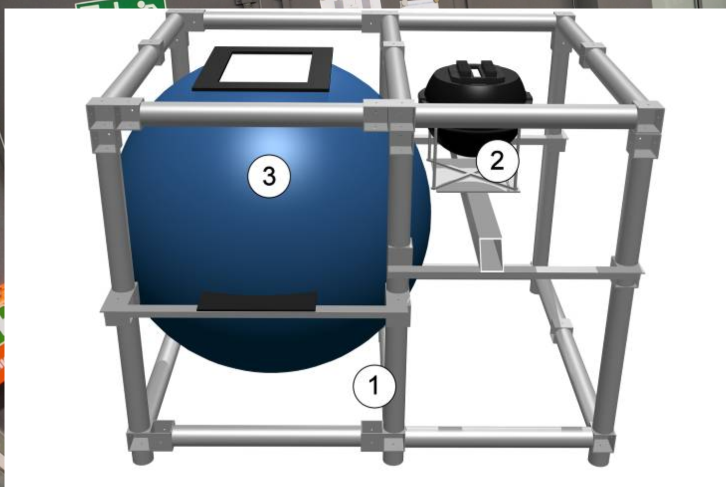



1. Pillar bearing instrument + adapter
2. Folding mirror
3. Assembly for geometric measurements
4. Assembly for spectral measurements

5. Sensor ROSIS
6. CHB adapter

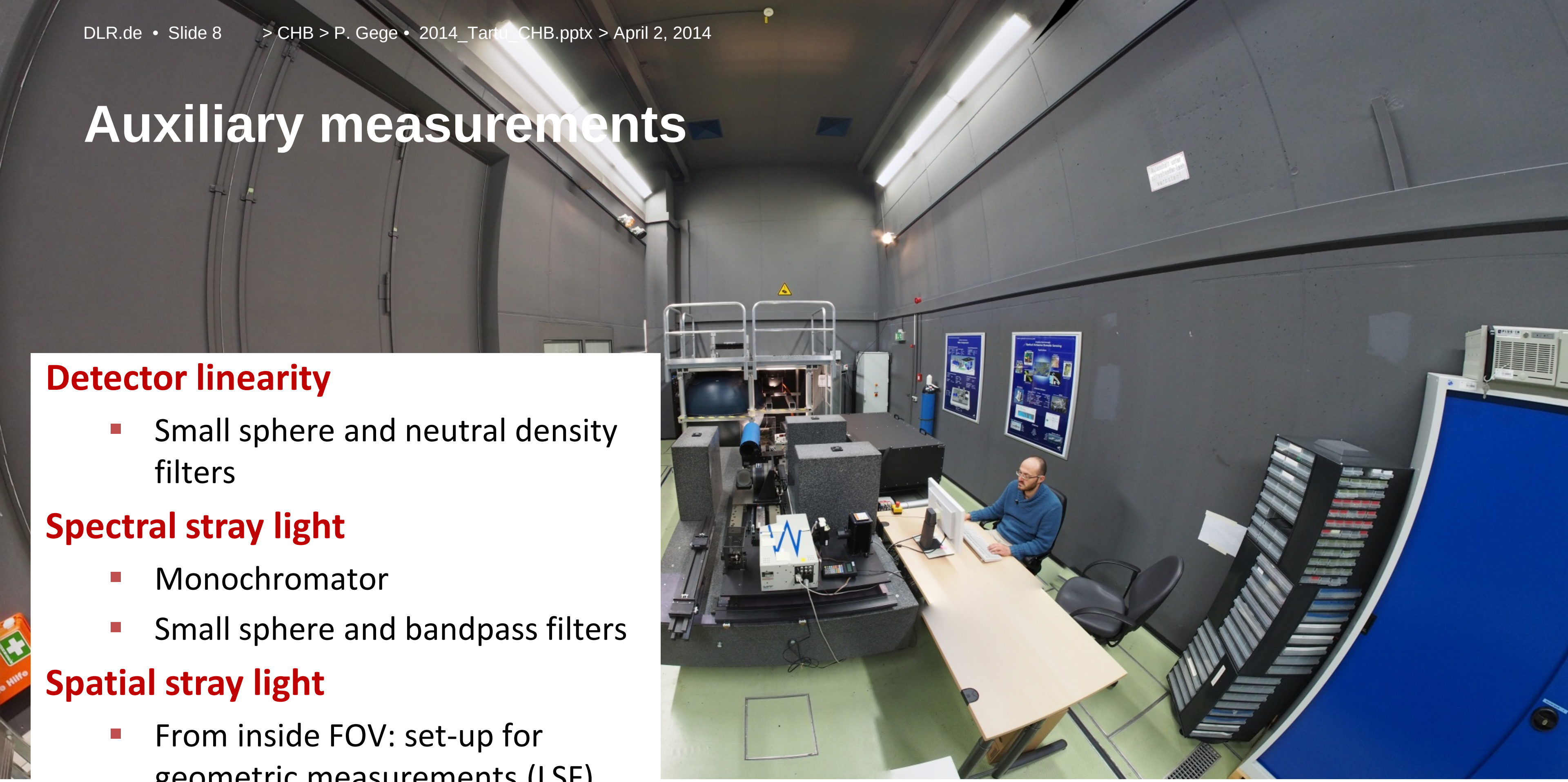
DLR

# Radiometric measurements




1. Frame
2. Small integrating sphere for absolute calibration
   4 lamps, diameter 50 cm, aperture 4 x 20 cm², originally traceable to PTB
3. Large integrating sphere for relative calibration (flatfielding)
   18 lamps, diameter 165 cm, aperture 40 x 55 cm²

# Auxiliary measurements



## Detector linearity

- Small sphere and neutral density filters

## Spectral stray light

- Monochromator
- Small sphere and bandpass filters

## Spatial stray light

- From inside FOV: set-up for geometric measurements (LSF)
- From outside FOV: large sphere and reflectance targets

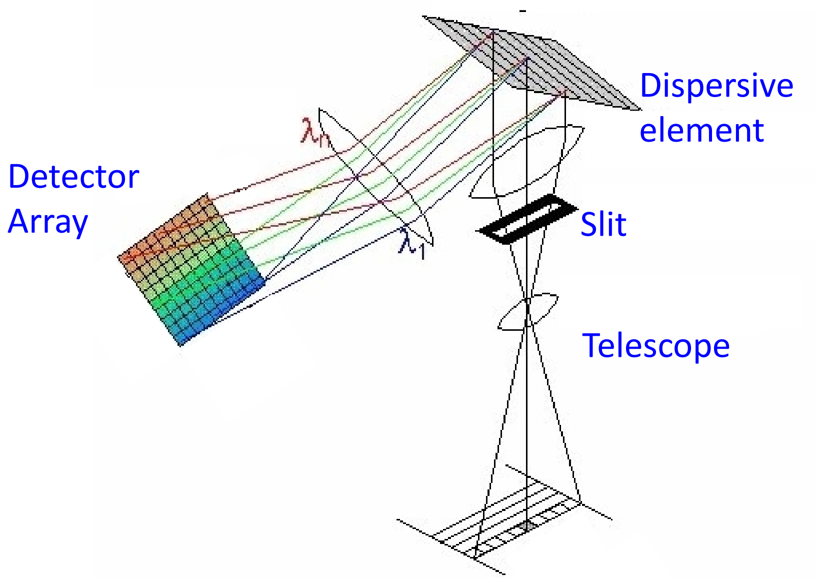
## Polarisation

- 3 linear polarisers 0.47 – 2.5 µm

# Principle of geometric and spectral measurements

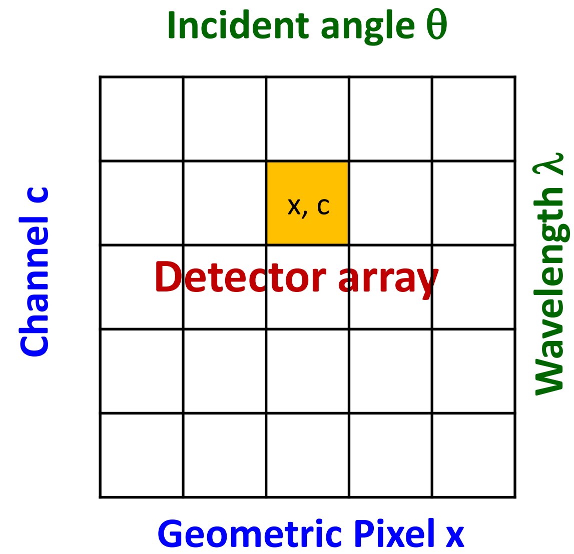
CHB was designed for pushbroom scanners

**Principle of a pushbroom scanner**




**Sensor characterisation** uses relative intensity (I) measurements at well defined incident angles $\theta$ and wavelengths $\lambda$:

- Geometric: $I_{x,c}(\theta, \lambda)$ vs. $\theta$
- Spectral: $I_{x,c}(\theta, \lambda)$ vs. $\lambda$



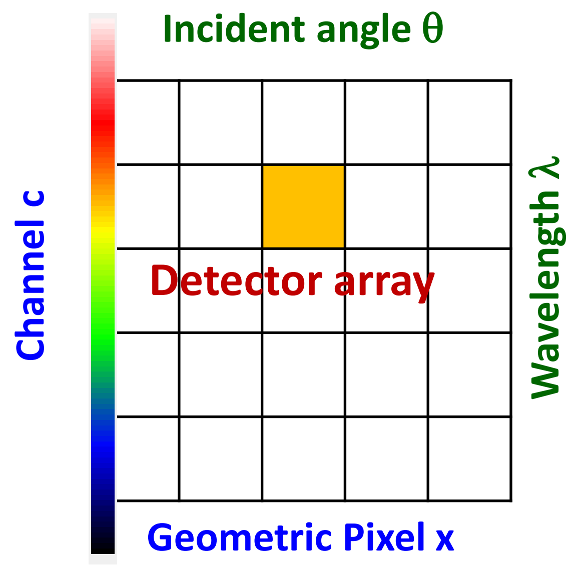

**Calibration** is the inverse:

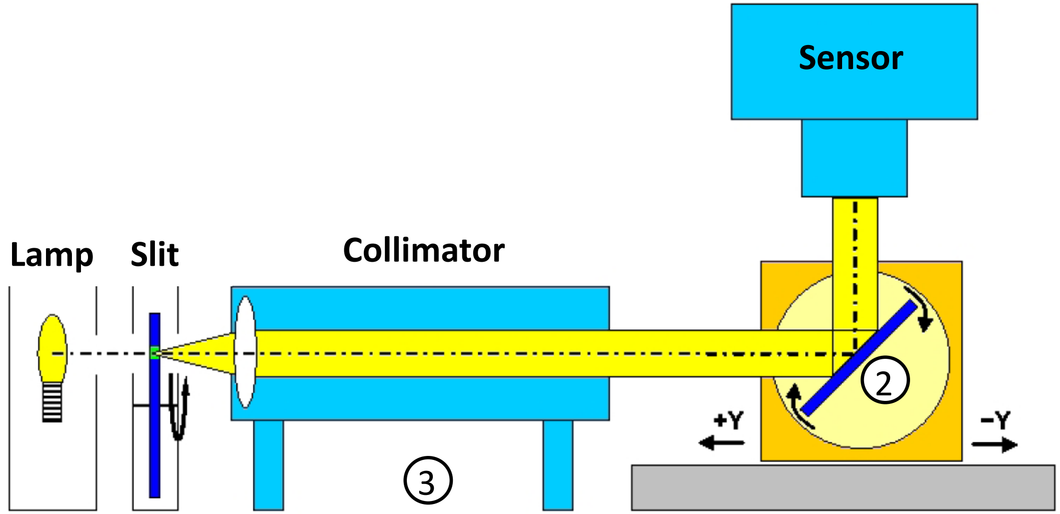
- Geometric: $\theta(x, c)$
- Spectral: $\lambda(x, c)$

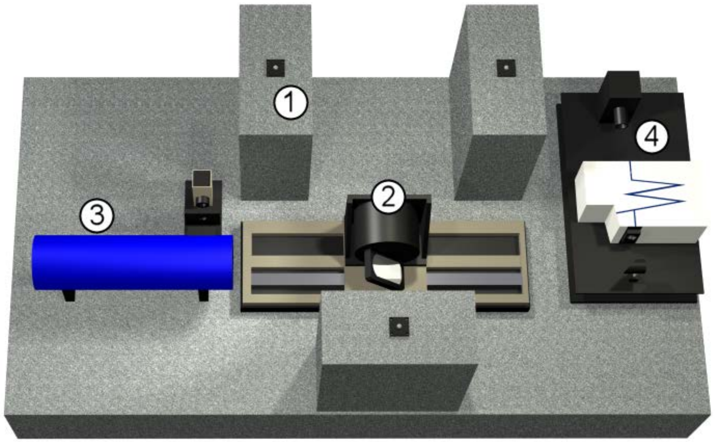
DLR

# Set-up for geometric measurements

- Quartz halogen lamp illuminates narrow slit
- Collimator produces nearly parallel light beam
  - divergence << IFOV
  - cross section > sensor aperture
- Folding mirror scans over pixels

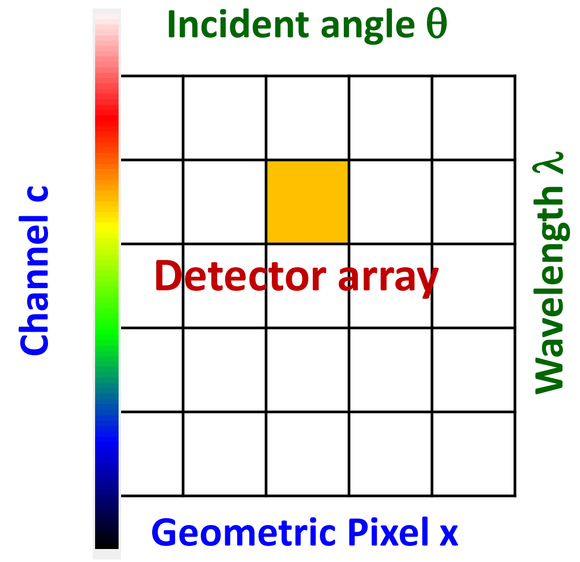


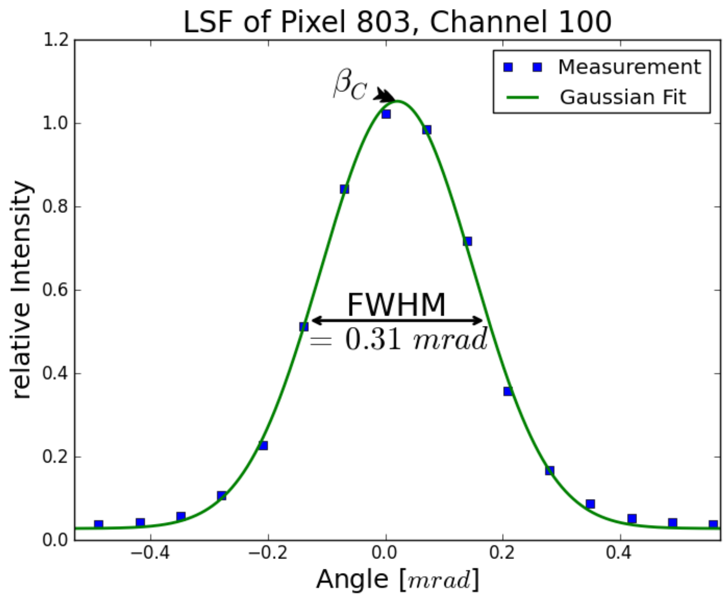



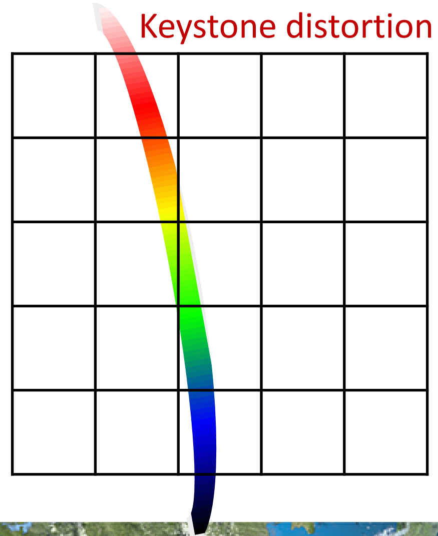



# Line spread function (LSF)

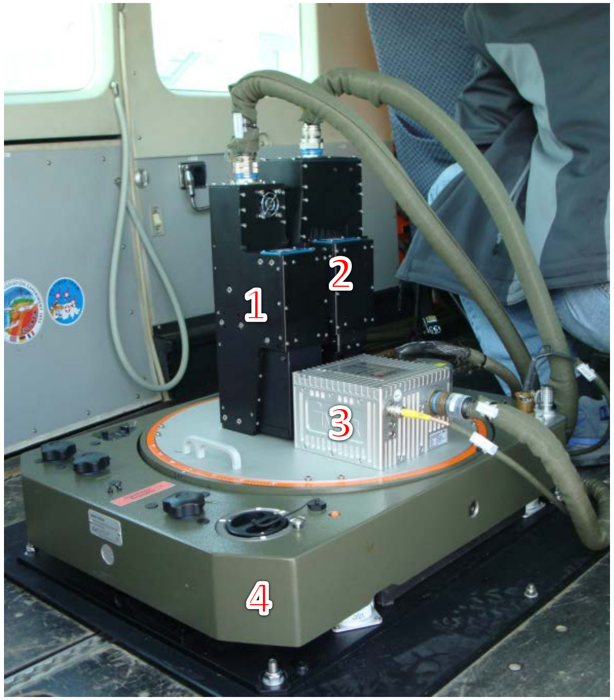
- LSF(x, c) is the relative response of pixel x and channel c as function of the incident angle
- Derived information
  - Viewing angle relative to reference pixel
  - Angular resolution = IFOV = FWHM
  - Keystone: each pixel has own LSF



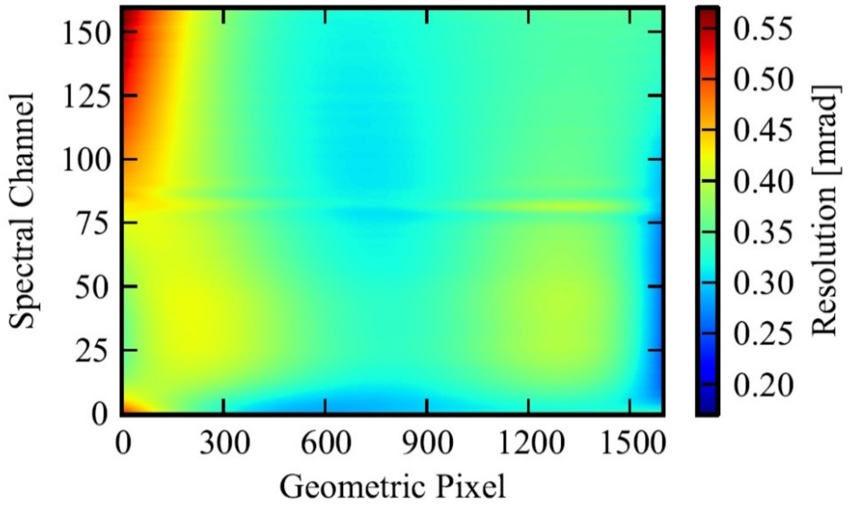
# Results for HySpex VNIR-1600



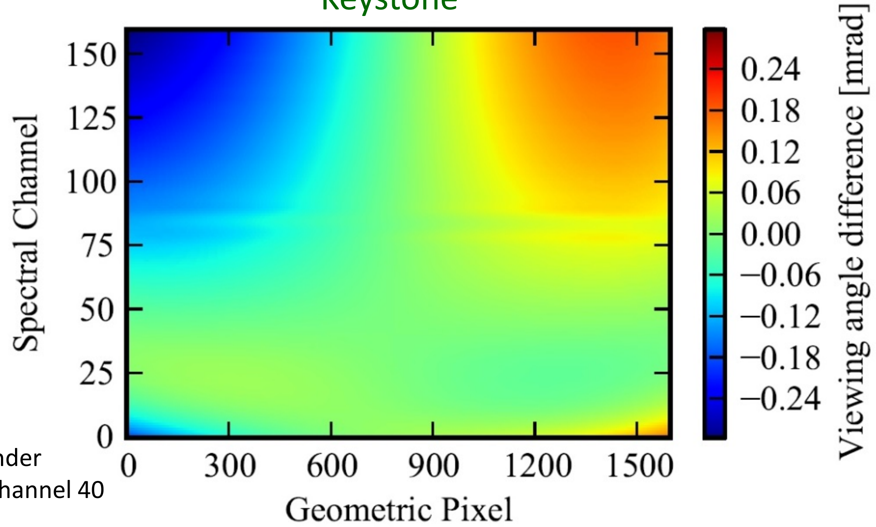

**HySpex system mounted in DLR aircraft**

**1** VNIR camera
**2** SWIR camera
**3** Navigation system
**4** Stabilized platform

Across-track resolution




Keystone

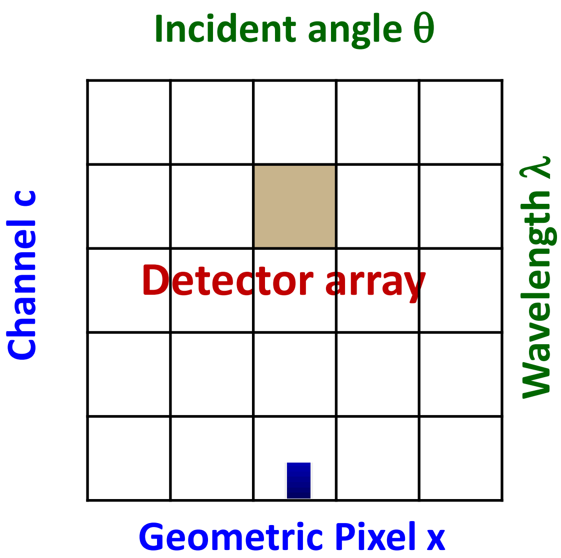


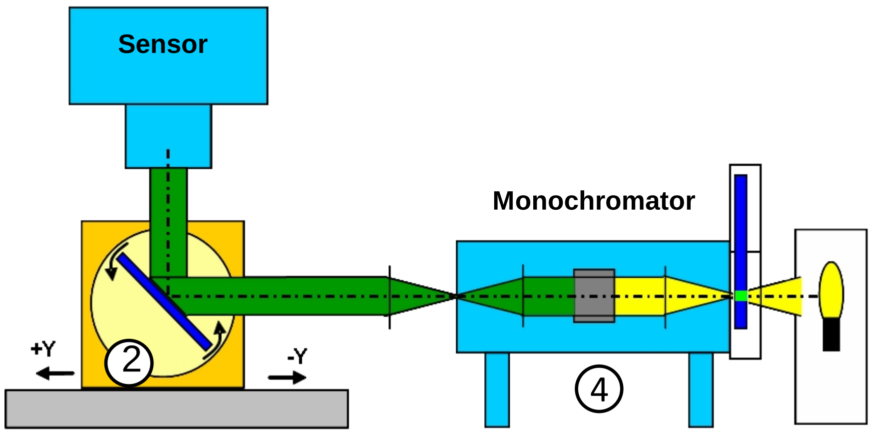

With FOV expander
normalized to channel 40

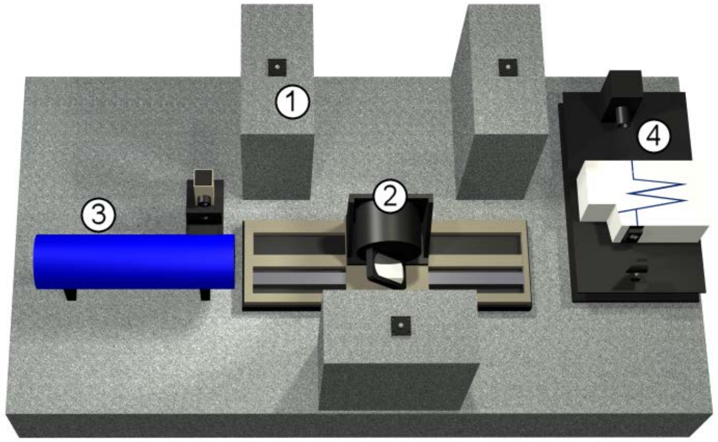
DLR

# Set-up for spectral measurements

- Monochromator scans over wavelength
  - Range: 0.38–2.5 µm
  - Uncertainty: ± 0.1 nm
  - Spectral bandwidth: > 0.1 nm
- Parabolic mirror focusses beam
  - divergence ≥ IFOV
  - cross section > sensor aperture
- Folding mirror selects some pixels

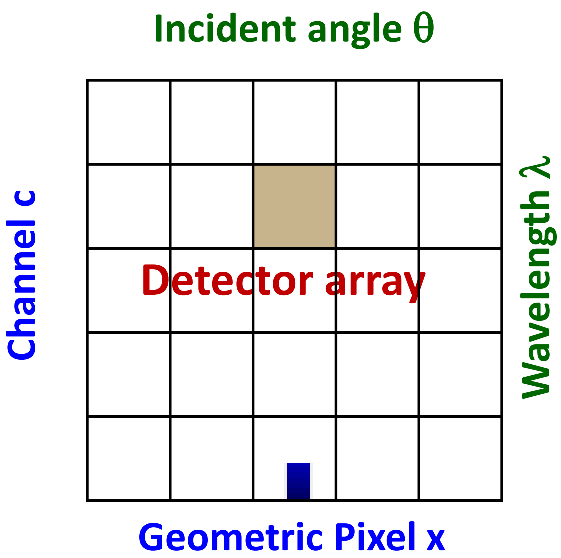


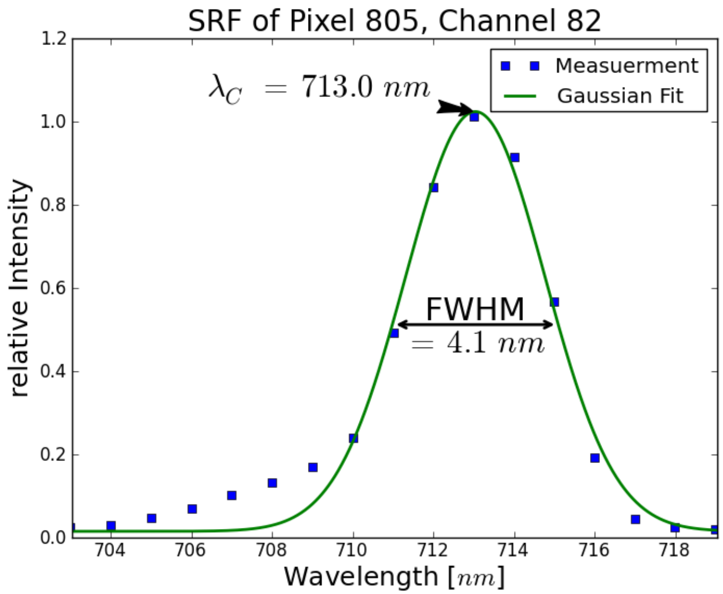



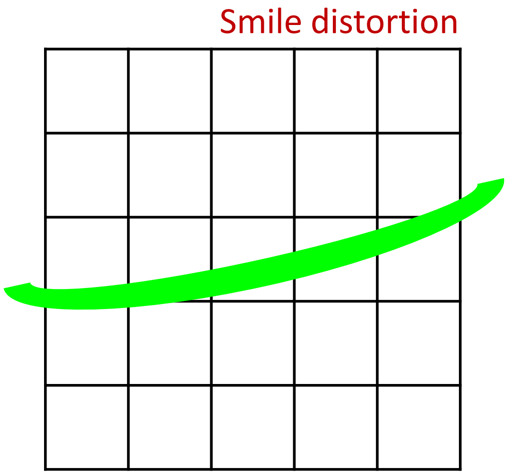



# Spectral response function (SRF)

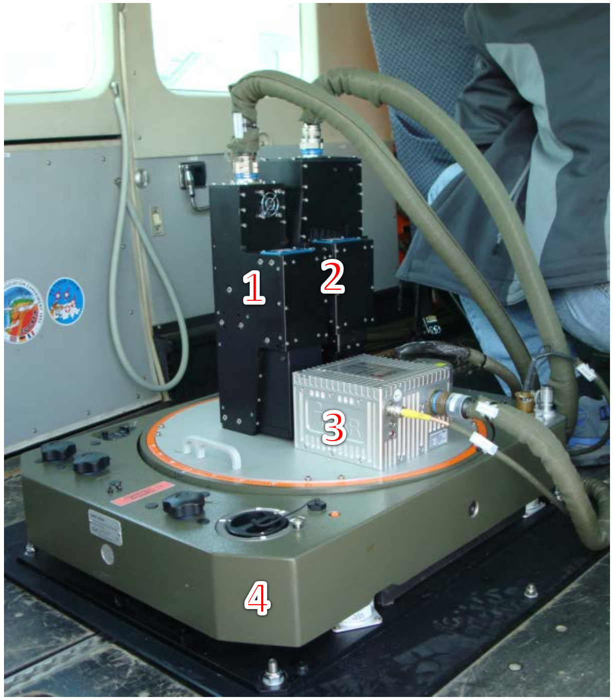
- SRF(x, c) is the relative response of pixel x and channel c as function of wavelength
- Derived information
  - Center wavelength
  - Spectral resolution = FWHM
  - Smile: each pixel has its own SRF



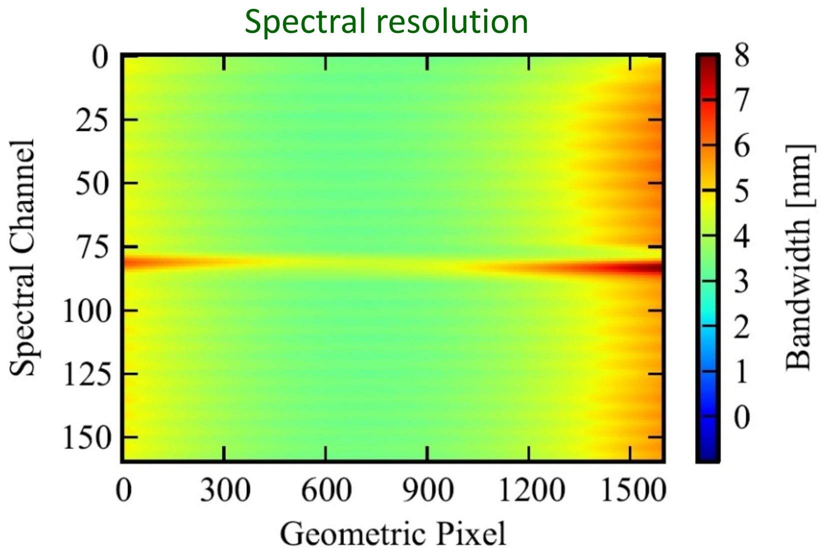



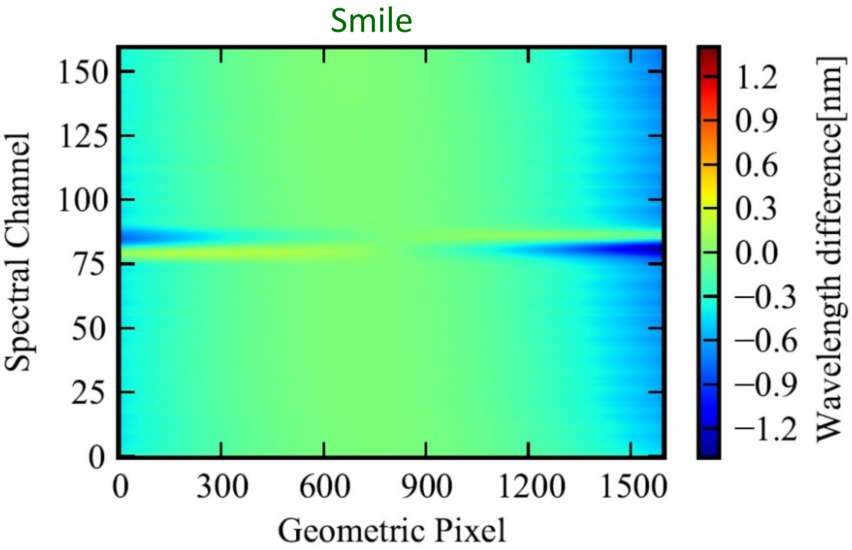
# Results for HySpex VNIR-1600




**HySpex system mounted in DLR aircraft**

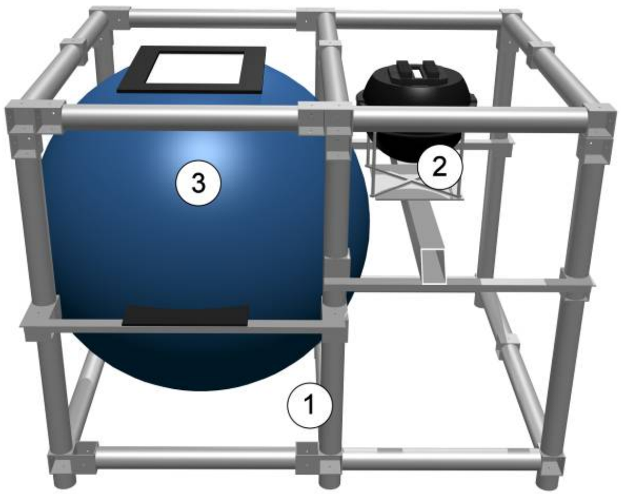
**1** VNIR camera
**2** SWIR camera
**3** Navigation system
**4** Stabilized platform

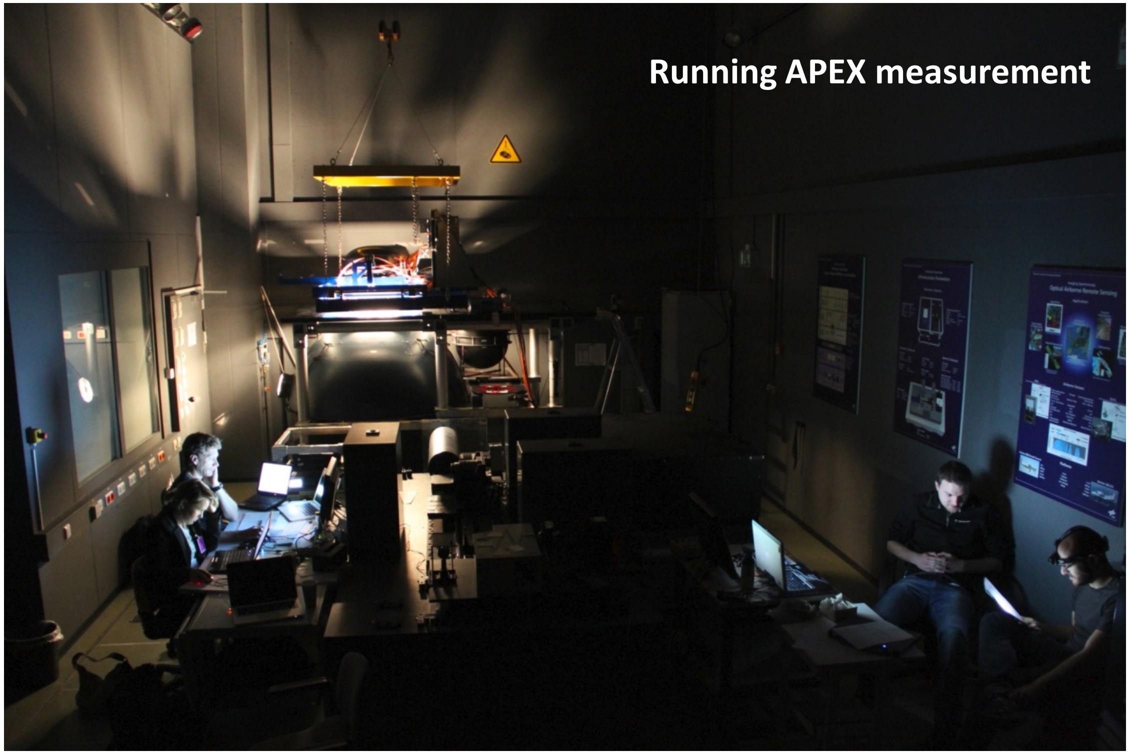


# Set-up for radiometric measurements

- Sensor is mounted to integrating sphere
  - Large sphere for relative calibration
  - Small sphere for absolute calibration

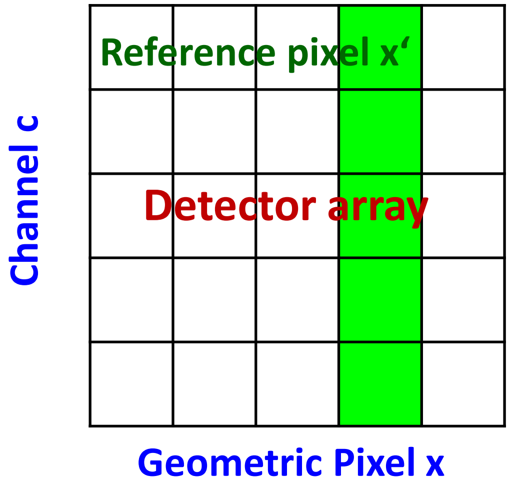


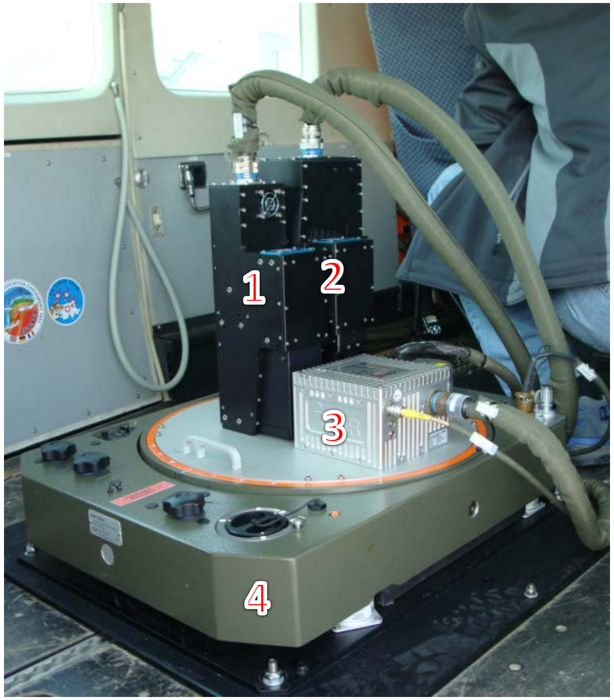

DLR

# Radiometric response

- **Relative response** of pixel x are the sensor signals S(c) relative to a reference pixel x' when all pixels are illuminated with the same intensity:
  - $\rho(x, c) = S(x, c) / S(x', c)$
- **Absolute response** is the ratio of the measured signal to the radiance L from a calibrated light source and integration time t:
  - $r(x', c) = S(x', c) / [t \times L(x', c)]$
- For pixels not illuminated by the L source:
  - $r(x, c) = r(x', c) / \rho(x, c)$
- **Effects influencing response**
  - Polarization
  - Noise
  - Nonlinearity: S not always proportional to L or t
  - Stray light: S(x, c) affected by light from angles and wavelengths outside the ranges of element (x, c)
  - Electronics: quantization, smear, memory effects

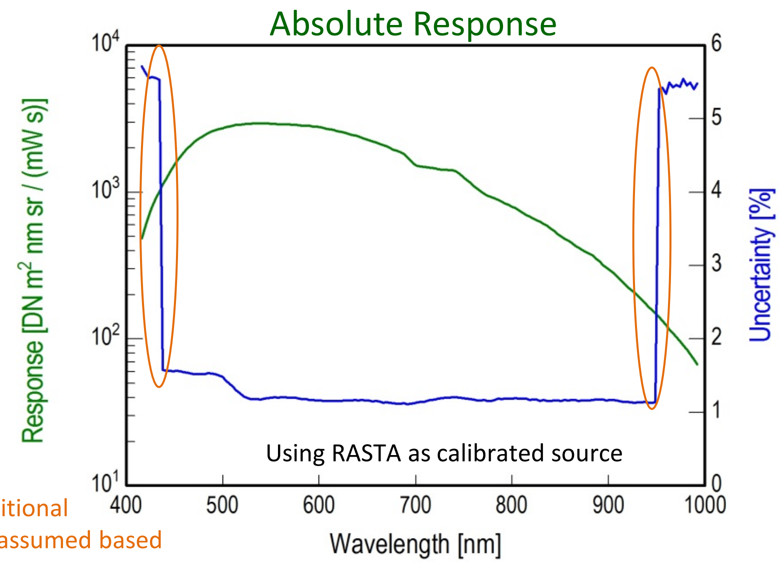


# Results for HySpex VNIR-1600

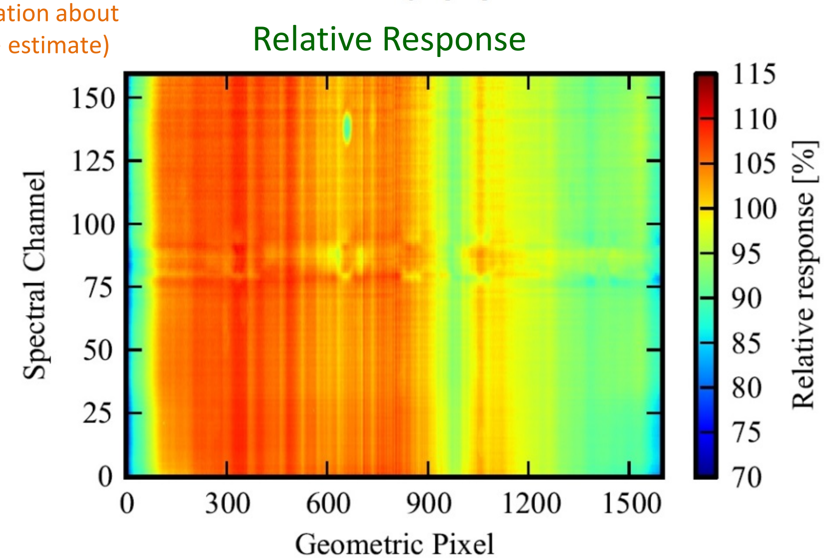



**HySpex system mounted in DLR aircraft**

**1** VNIR camera
**2** SWIR camera
**3** Navigation system
**4** Stabilized platform



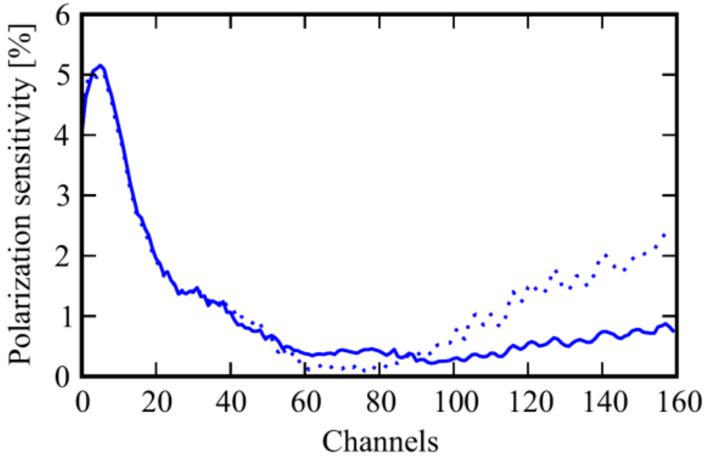

At signals < 300 DN additional uncertainty of 5 % was assumed based on manufactorer information about non-linearity (worst-case estimate)



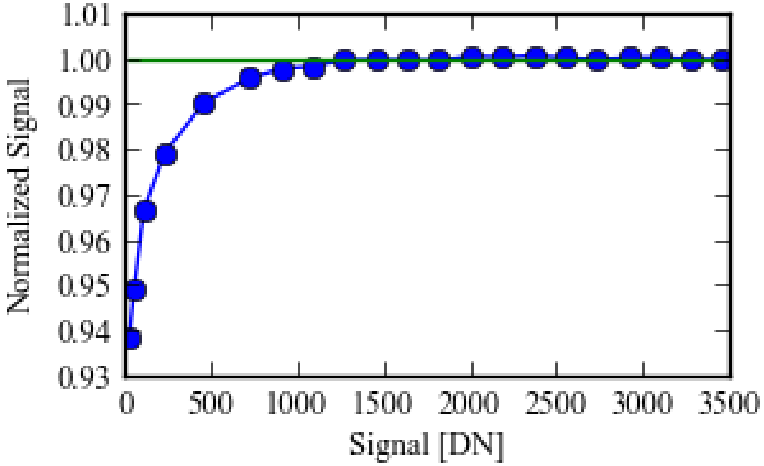

DLR

# Results for HySpex VNIR-1600

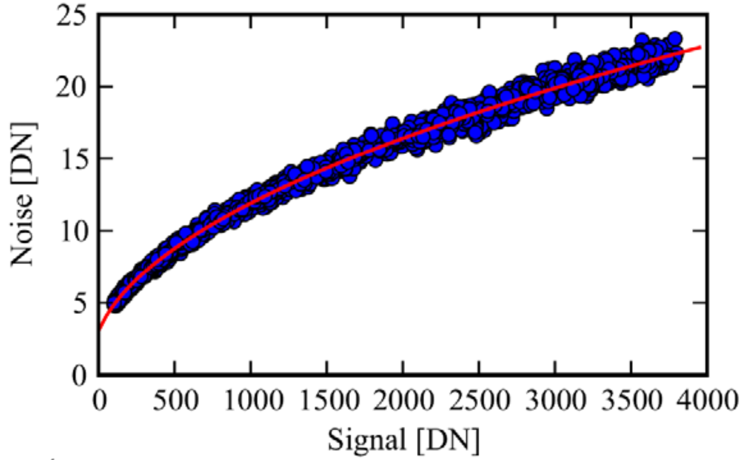
Sensitivity to polarization



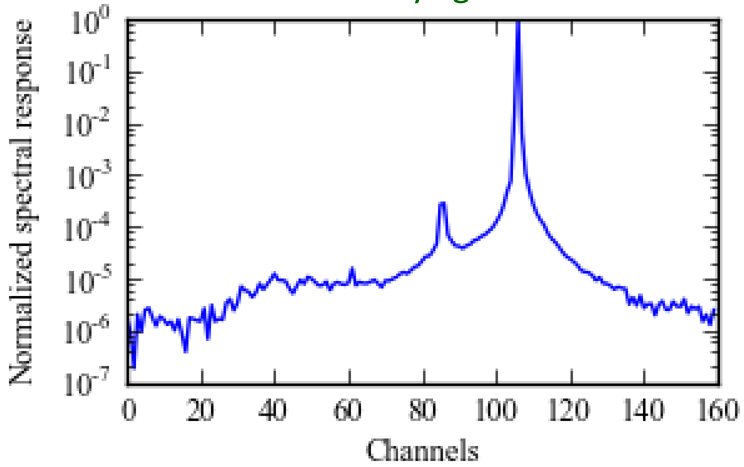

Nonlinearity




Noise




Stray light

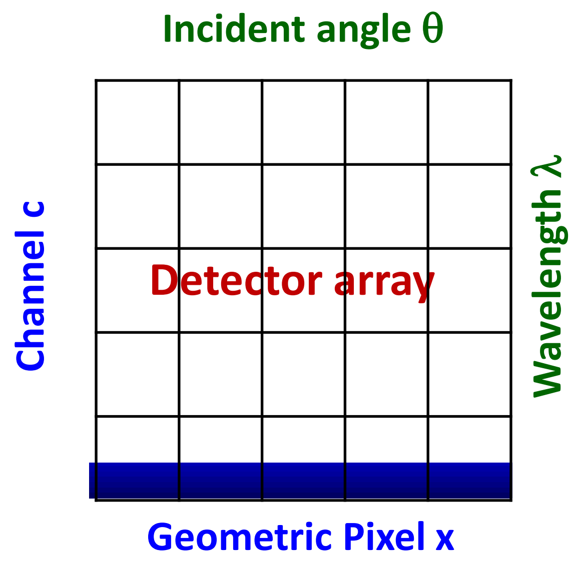


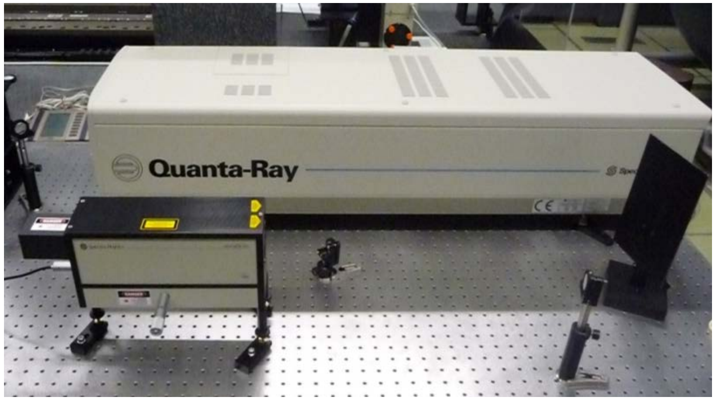
# Recent upgrades

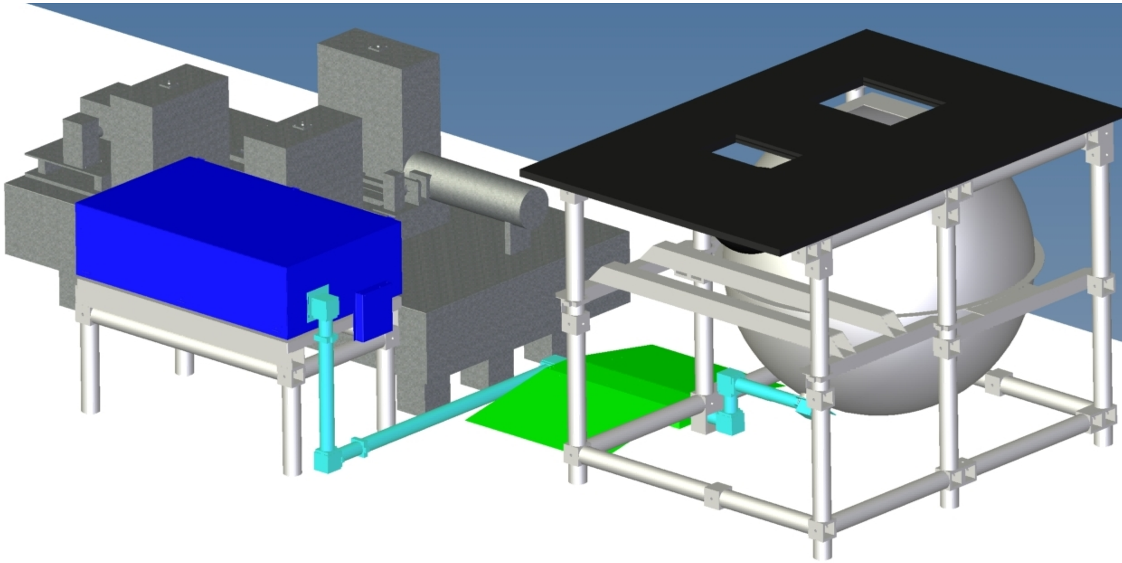
**Tunable laser**

**For spectral calibration and stray light measurements**

- Tunable from 410 – 2550 nm
- Spectral linewidth fix at 0.5 – 2.5 nm
- 10 ns pulses @ 10 Hz
- Illumination of instruments via integrating sphere



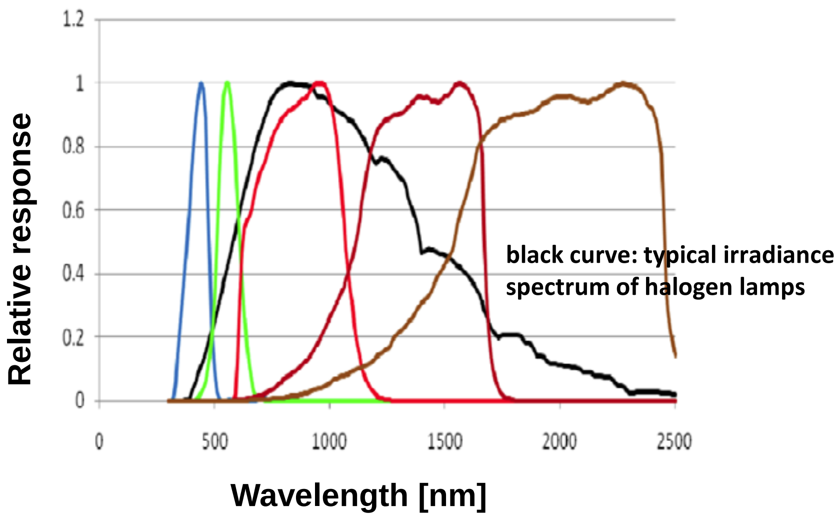



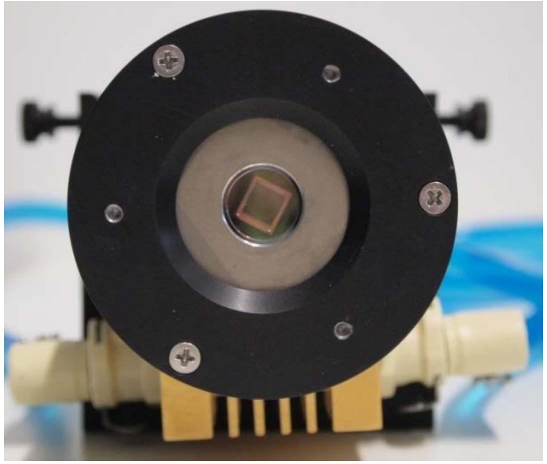
# Recent upgrades

**6 precise filter radiometers**

**For radiometric measurements and monitoring of stability**

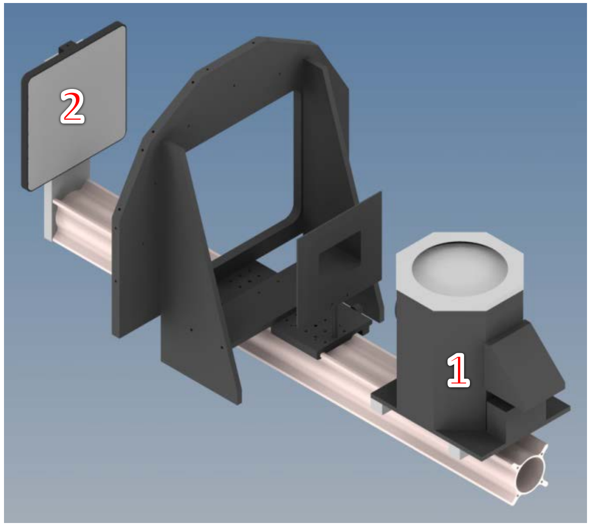
- Much more stable than lamps
- Temperature stabilized to <0.001 °C during 1 h
- Large dynamic range: 8 decades



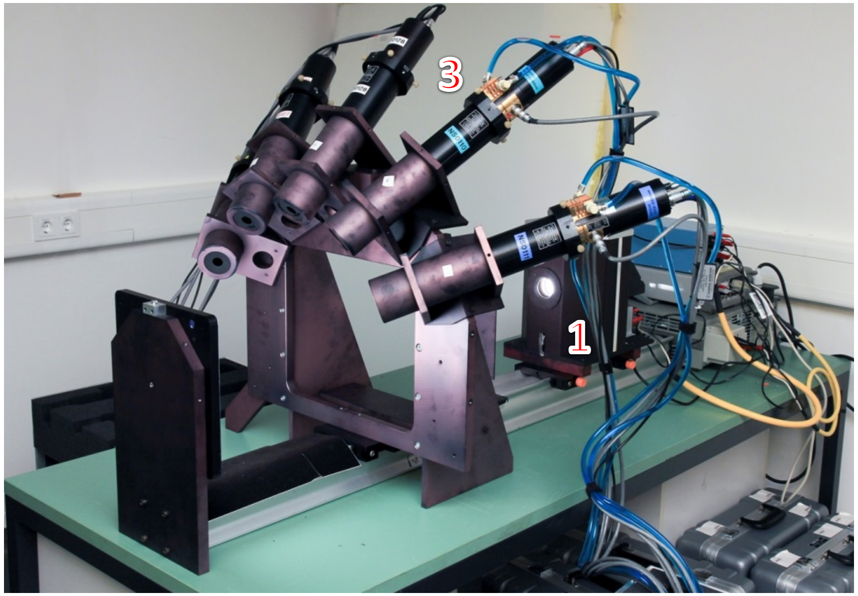
# Recent upgrades

**Radiance Standard RASTA**
**New radiance standard of CHB**




1. Light source: FEL 1000 W halogen lamp
2. Diffuser: Spectralon panel (25 x 25 $cm^2$ )
3. Monitoring of stability: 5 filter radiometers

- Calibration at PTB:
  - FEL lamp: irradiance
  - Spectralon panel: reflectance
  - Complete system: spectral radiance



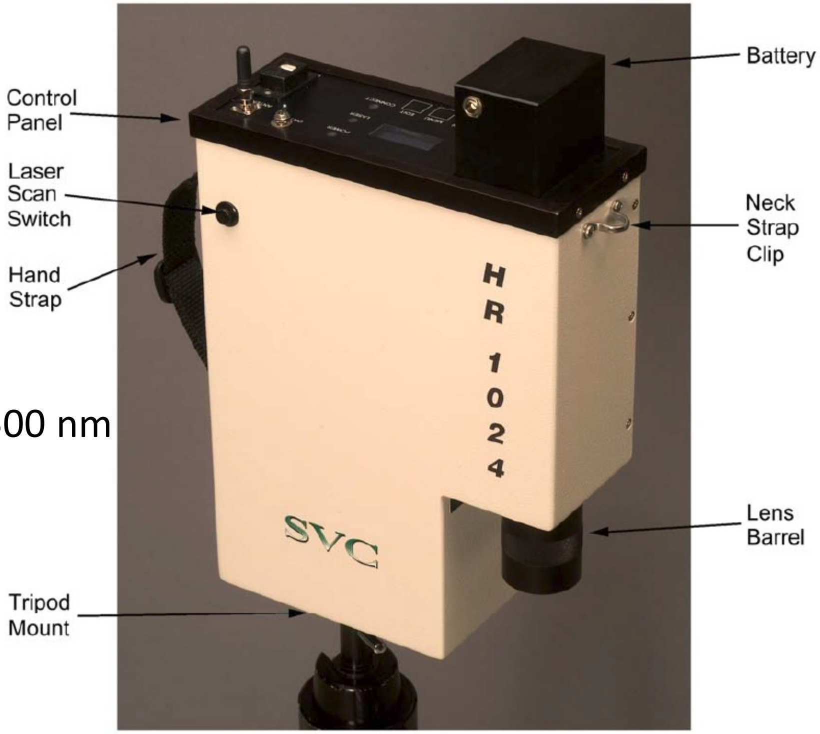

DLR

# Recent upgrades

**Spectrometer SVC HR-1024i**

**To calibrate radiance sources against RASTA**

- Range: 350 – 2500 nm
  - 512 Si Detectors @ 350 – 1000 nm
  - 256 InGaAs Detectors @ 1000 – 1850 nm
  - 256 Extended InGaAs Detectors @ 1850 – 2500 nm
- Spectral resolution (FWHM)
  - ≤ 3.5 nm @ 350 – 1000 nm
  - ≤ 9.5 nm @ 1000 – 1850 nm
  - ≤ 6.5 nm @ 1850 – 2500 nm
- Field of view
  - 2°, 4°, 8°: lenses
  - 25°: glas fibres with lengths of 1.15 m, 3 m
- Digitization: 16 bit



# Equipment for water applications

## Laboratory instruments

- Varian Cary-1 UV/VIS spectrophotometer (190-900 nm) **– old**
  - Used to measure CDOM absorption
- PerkinElmer Lambda 1050 UV/VIS/NIR spectrophotometer (190-3300 nm) **– new**
  - Used to measure CDOM and phytoplankton absorption
- Horiba Fluoromax-4 fluorescence spectrometer (220-850 nm) **– delivery May 2014**
  - Used to measure CDOM and phytoplankton fluorescence (EEM)

## Field instruments

- TriOS RAMSES (190-900 nm)
  - Used to measure $L_u$, $E_u$, $E_d$ in air and under water
- Spectra Vista SVC HR-1024i spectrometer (350-2500 nm)
  - Used to measure $L_u$, $E_d$ in air
- Microtops sun photometer and ozonometer
  - Used to derive atmospheric ozone, water vapour and aerosol optical depth

# Conclusions

- CHB was designed for airborne imaging spectrometers (line scanners)
  - Fully computer controlled including data evaluation
  - It was used for APEX, ROSIS, HySpex, AISA
  - Cooperation with PTB assures state-of-the-art accuracy and traceability
  - ISO-9001 certified in 2013
- CHB is equipped to measure optical properties
  - Transmission, reflectance, absorption, fluorescence
- Recent upgrades improved
  - Accuracy of radiometric calibration
  - Speed of spectral measurements
  - Dynamic range of stray light measurements
- CHB is partly suited for field spectrometers
  - Radiometric calibration: feasible for radiance in air, but not for irradiance and not in water
  - Spectral characterization: feasible; range and accuracy depends on instrument
  - Geometric characterization: feasible; range depends on instrument
  - Stray light: estimate possible, but no full characterization
  - Linearity: feasible
  - Polarization sensitivity: feasible